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Chapter 23

CHARACTERIZATION AND LOW-COST REMEDIATION OF SOILS CONTAMINATED BY TIMBERS IN COMMUNITY GARDENS

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ABSTRACT

Urban community gardens worldwide provide significant health benefits to those gardening and consuming fresh produce from them. Urban gardens are most often placed in locations and on land in which soil contaminants reflect past practices and often contain elevated levels of metals and organic contaminants. Garden plot dividers made from either railroad ties or chromated copper arsenate (CCA) pressure treated lumber contribute to the soil contamination and provide a continuous source of contaminants. Elevated levels of polycyclic aromatic hydrocarbons (PAHs) derived from railroad ties and arsenic from CCA pressure treated lumber are present in the gardens studied. Using a representative garden, we 1) determined the nature and extent of urban community garden soil contaminated with PAHs and arsenic by garden timbers; 2) designed a remediation plan, based on our sampling results, with our community partner guided by public health criteria, local regulation, affordability, and replicability; 3) determined the safety and advisability of adding city compost to Boston community gardens as a soil amendment; and 4) made recommendations for community gardeners regarding healthful gardening practices. This is the first study of its kind that looks at contaminants other than lead in urban garden soil and that evaluates the effect on select soil contaminants of adding city compost to community garden soil.

Keywords: Urban community gardens, creosote timbers, CCA lumber, PAHs, soil, compost, healthy gardening

1. INTRODUCTION

The early history of urban gardens in the United States is one of food production on public land in response to war, economic depression, and short-lived civic reform movements. With the exception of some creative garden projects promoted by public housing authorities in the 1950's

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and 60's for the purposes of beautification and tenant pride, the tradition of urban gardening was largely abandoned in the United States after World War II, when the focus of residential and commercial growth became the new suburbs (Hynes and Howe, 2002). Older center cities were left to decline as the middle and upper middle class populations left urban neighborhoods, with financial and commercial institutions following, to push the edges of metropolitan growth into peri-urban and once-rural areas. Failed urban renewal programs further demolished neighborhoods and frequently left swaths of vacant land, disproportionately in African-American neighborhoods (Fullilove, 2001). Between 1960 and 1990, about 30% of residential buildings in Harlem, New York became derelict and uninhabitable. By the mid-1990s Chicago, Illinois had 70,000 vacant lots; 18% of once-productive industrial land is vacant (Hynes, 1996). The population of center city Philadelphia, the oldest industrial U.S. city, was 2.2 million after World War II; today it is 1.6 million and shrinking. Philadelphia has more than 30,000 vacant lots and 21,000 abandoned houses (Gowda, 2002).

Over the past four decades, a broad-based community garden and urban agriculture movement has arisen in hundreds of US center and inner cities for the purposes of neighborhood revitalization, food-growing, and youth development. This "second wave" of community garden movement was initiated and driven by local communities with the financial and organizational assistance of local governments, foundations, and non-profit organizations. A growing body of social science, urban design, and public health research has demonstrated that urban community gardens and urban farms contribute significantly to the livability of cities by providing nutritious and affordable food, psychological and physiological health benefits, social cohesion, crime prevention, recreation and youth development, particularly in low-income and multi-ethnic communities (Hynes and Howe, 2002).

Today, some 40 years after the first community gardens were organized, we do not have a complete census of urban gardens. However, we do have survey data, informed estimates, and in-depth case studies which suggest that the growth and diversity of the many efforts to revive horticulture and agriculture for the purposes of community development and community food security in U.S. cities are successful.

The American Community Gardening Association (ACGA) estimates that municipal governments and non-profit organizations operate 18,000 community gardening programs in hundreds of cities and towns (personal communication, 2007). The most recent survey of community gardens, in which ACGA polled residents of 38 cities across the United States, revealed some interesting issues and trends. First, despite a lack of security in land ownership (only 5.3% of the 6020 community gardens surveyed were securely owned or placed in trust), more gardens are being created in these cities than are being lost to economic development or lack of interest. Second, the primary reported use of community gardens is the neighborhood garden in which the land is divided into numerous plots cultivated for vegetables, fruits, herbs, and flowers by individuals and households. Community gardens are typically built on vacant residential land that is divided into multiple beds that are framed by wood timbers. A community member applies for a plot and, once given it, may continue to garden in the same plot for multiple years, or move to another. Most community gardens are owned and maintained by not-for-profit organizations and local municipalities.

Other potential uses and kinds of community gardens, such as ones in public housing, senior housing and schools, were reported in much smaller numbers. The survey also revealed the small but increasing use of community gardens as job training sites for youth and as market gardens from which plants and plant-products are sold, often in local farmers' markets (American Community Gardening Association, 1998). There has also been a reinvigoration of local food production in response to a general awareness of environmental sustainability and individuals' seeking ways to decrease their carbon footprint and support local agriculture. Most recently, the rapid rise of food costs, driven in part by the price of oil and the rise of ethanol production, has generated even more interest in community gardening.

The community gardens of the 1960s and 70s were a quick, efficient, and low-cost way to address urban blight and to stem the decline of a neighborhood, block-by-block. In that period, rubble was removed or bulldozed into cellar holes and soil was trucked in, for a surface growing medium. Soil providers were as disparate as the Army Corps of Engineers and peri-urban farmers. Salvaged railroad ties were often used to frame gardens, and they were later augmented with or replaced by chromated copper arsenic (CCA) lumber. Other than a growing awareness of lead in soil from air deposition and from paint on old housing that formerly stood on most of the garden sites, there was little thought given at the time to potential soil contaminants, such as creosote in railroad ties and arsenic in CCA lumber. Gardeners and others who consume produce grown in gardens with contaminated soils are exposed to the contaminants directly, through the pathways of incidental ingestion, dermal contact with the soils and through inhalation of dusts. Exposure to contaminants can also occur directly through ingestion of unwashed plants onto which contaminated soil has deposited, or through ingestion of plants that have taken up contaminants through their root systems (Chaney et al. 1984, Finster et al. 2004, Hough et al. 2004, Samsoe-Peterson et al. 2002). Health risks associated with these behaviors have been examined and for most backyard or urban gardeners, the most important pathways are the ingestion of contaminants deposited on plants and the consumption of metals, specifically lead, taken up by leafy plants and consumed (Finster et al. 2004, Hough et al. 2004, Sipter et al. 2008).

Several studies have examined the levels of lead in urban community gardens and yards and have shown elevated concentrations of lead (Clark et al. 2006, Hynes et al 2001, Litt et al. 2002). This is, to our knowledge, the first published study to examine polycyclic aromatic hydrocarbons (PAHs) from creosote and arsenic from CCA lumber as contaminants in urban community gardens.

2. MATERIALS AND METHODS

2.1 Study Background

In 2004, Boston University researchers were asked for technical assistance by the Boston Natural Areas Network (BNAN), a non-profit organization managing over 50 community gardens in Boston, regarding concerns about polycyclic aromatic hydrocarbons (PAHs) in community garden soil. Polycyclic aromatic hydrocarbons are a group of more than 100 chemicals formed during incomplete combustion of organic substances such as oil, garbage, and coal. They are also found in many industrial and consumer materials and by-products including coal tar, asphalt, tobacco smoke, and creosote. Elevated levels of PAHs had been detected in select soil samples of one Boston garden. Accordingly, BNAN requested that the researchers develop a low-cost research plan that would determine the levels of PAHs in both a "worst case" garden and in a garden more representative of those they manage overall. Additional concerns regarding arsenic led to the inclusion of a third garden in which to evaluate the potential impact of CCA lumber to the soil. Soil testing for CCA lumber was added to the research plan. The work presented here is the result of a university-community research partnership, in which we sampled and analyzed soil from a "worst-case" and two representative community gardens in Boston containing creosote railroad ties and CCA lumber. Assistance with laboratory analysis was provided by the United States Environmental Protection Agency (EPA) Region 1 Laboratory and Wellesley College, Department of Geosciences.

Our research objectives were fourfold: 1) to characterize the nature and extent of urban community garden soil contaminated with PAHs and arsenic by garden timbers; 3) to determine the safety and advisability of adding city compost to Boston community gardens as a soil amendment; 2) to design and evaluate a remediation plan with our community partner guided by public health criteria, local regulation, affordability, and replicability; and 4) to make recommendations for community gardeners regarding healthful gardening practices. This is the first study of its kind to look at contaminants other than lead in urban community garden soil and to evaluate the effect on select soil contaminants of adding city compost to the soil. The findings, along with a recommended remedial action plan for PAHs, are relevant to other cities with community gardens and urban farms and support the role of urban horticulture in contributing to healthy, livable cities. The remediation plan focuses on PAHs for two reasons. First, three quarters of the soil samples analyzed for arsenic had levels below the detection limit of the analytical instrument. Second, the concentrations of PAHs, their patterns of migration in soil, and the state standards for total and individual PAHs in residential soil drive the remediation plan in urban gardens with soil contaminated by both creosote- and CCA-laden timbers.

2.2 Garden Selection

Three urban community gardens in Boston were selected for sampling through an iterative process of criteria development and garden selection between the researchers and the community organization, Boston Natural Areas Network (BNAN). Garden 1, which is located near a major road and municipal bus stop, was selected as a worst-case scenario for reasons of having a continuous source of PAHs from both ambient air and creosote timbers used as plot dividers throughout the garden. Otherwise its size, use, and garden practices resemble gardens 2 and 3. Gardens 2 and 3 were selected to represent typical Boston urban gardens in terms of size, use, sources of PAHs and arsenic, and applications of municipal compost provided annually to BNAN gardens. Neither was located on a major thoroughfare. The site history of Gardens 2 and 3 suggested that they were free of any unique PAH or arsenic source (other than creosote timbers and CCA lumber); and both had undergone compost and tilling practices common to most other Boston community gardens. In addition to meeting the predetermined selection criteria, Garden 2 was also being considered as a candidate to receive soil and site remediation funds, making it of particular interest to BNAN to include in the study.

Community Garden 1 spans approximately 19,000 ft^2 and contains 34 variably-sized garden plots. It is bordered by a major road and bus stop, a parking lot, and a liquor store. Developed in the 1970s, the garden was built on land previously occupied by abandoned homes. Creosote-impregnated railroad ties, now cracked and weathered, were installed at that time as borders for garden plots.

Community Garden 2 occupies about 23,000 ft^2 and contains 27 fairly large, variably-sized plots. It is bordered by two residential streets, a dog park and the backyards of nearby homes and it is believed to have a history of residential land use. Creosote timbers, installed approximately 20 years prior to initiation of this project, border half of the gardening plots. The timbers show signs of weathering, but are more intact than those in Garden 1. CCA lumber, installed approximately 12 years prior to initiation of this project, borders about one quarter of the plots, while the remaining one quarter are bordered by a mix of stone and brick.

Community Garden 3 is approximately 16,000 ft^2 in area and contains 27 variably-sized plots. These plots include three raised beds and four very narrow and long plots (~2x24 feet) that were intended to contain only decorative flowers and foliage, but which were subsequently used to grow vegetables, as well. All plots in this garden are bordered by CCA lumber, which was installed about 12 years prior to initiation of this project.

2.3 Sampling Design

Soil samples to be analyzed for PAHs were collected from three representative individual garden plots, one in Garden 1 and two in Garden 2. Each sampling plot was bordered on all four sides by creosote timbers. Composite samples (5 points per sample) were collected at two depths (0-4" and 4-8") and at four distances from the timbers (adjacent, 6", 12" and 18") for a total of eight “edge” samples per plot. For comparison, one “center” sample was collected from each plot to represent the remaining soil in the garden. These “center” samples were a collected to a depth of 8" and consisted of a composite of soil taken from the absolute center of the plot and from four surrounding points measured 30" from each of the four creosote timber borders. A background sample was collected from an undisturbed area in each of the two gardens. Background samples were collected at least ten feet from any garden plot or creosote timber. The sampling design was informed by pilot studies (unpublished) and literature suggesting the relative distance and depth of transport of PAHs in soil (Moret et al. 2007).

Soil samples to be measured for arsenic were collected from four garden plots, one in Garden 2 and three in Garden 3. Each plot was bordered on all four sides by CCA lumber. Composite samples (4-5 points per sample depending on the length of the plot) were collected at two depths (0-4" and 4-8") and at three distances from the timbers (adjacent, 3" and 6") for a total of 6 “edge” samples per plot. For comparison, one “center” sample, depth 8", was collected in each plot. These “center” samples consisted of a composite of soil from the absolute center of each plot and from four surrounding points measured 30" from each of the four CCA timbers. An exception to this was one very narrow plot in which the “center” sample was a composite of 5 points along the center of the plot, approximately one foot from the CCA timbers on either side. A background sample was collected from an undisturbed area in each of the two gardens. These background samples were collected at least ten feet from any garden plot or CCA timber. The distances and depths that were selected are based on pilot studies (unpublished) and the literature on transport of arsenic from CCA timber in soil (Stilwell et al. 2003).

2.4 Sampling Procedures and Analytical Methods

Surface samples (0-4") and root depth samples (4-8") were collected using a large stainless steel spoon and a steel bulb planter, respectively. Approximately equal sized portions from each composite point were mixed together in a large stainless steel bowl. An aliquot of each mixture was then spooned into 8 oz. amber jars and stored in an ice cooler until transport to the USEPA Region 1 Laboratory, or a commercial laboratory where analysis was performed. Field duplicates were collected at a rate of one per plot. Between samples, collection implements and mixing bowls were cleaned using distilled water and dried with paper towels.

All samples to be measured for PAHs and metals were extracted within 14 days of collection. Samples to be measured for PAHs were analyzed using gas chromatography-mass spectroscopy (GC-MS) operating in the full scan mode. The extraction and analysis followed Standard Operating Procedures (SOP) based on SW-846, 3545A, and 8270 methods and Contract Laboratory Program Statement of Work OLM04.2. Samples to be measured for arsenic and lead were analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Preparation and analysis followed SOP based on SW-846, 3050B and 6010B methods, respectively.

2.5 Statistical analysis of PAH levels in soil

All results below the reporting limit were replaced with a value equal to half the reporting limit for that sample and compound if the analyte was detected in at least one sample. Duplicate samples were averaged. Evaluation of histograms revealed the data to be log-distributed and, thus, the data were log-transformed prior to analysis. Geometric means (GM) and geometric standard deviations (GSD) were calculated for each compound in each sample. T-tests were performed comparing (log) PAH concentrations in background samples to those in samples taken at each distance from the timber. Differences in (log) PAH concentrations by plot and by depth were determined using analysis of variance (ANOVA). Spearman’s rank correlation was calculated to evaluate the effect of distance from the creosote timbers (as a continuous variable) on (log) PAH concentrations.

2.6 Compost Analysis

Over the course of the project, four batches of Boston’s city compost that did not contain street sweepings and one that did contain street sweepings were analyzed by a contract laboratory for the presence of nitrogen, phosphate, individual PAHs (Method 8270), total metals (Methods 6010 and 7471), herbicide activity, phthalates and chemical/physical parameters. The compost is comprised of leaf and grass clippings which are collected curbside, placed in windrows at the compost facility, mixed with clean sand, turned and ready for use within a year. In order to characterize the compost, representative samples from each windrow was collected by combining four individual samples from each quadrant of the windrow. In the case of the compost used for remediation of timber-derived contaminants in soil in this study, it was characterized by three samples, each reflecting a composite of six pooled samples. Samples were collected with clean metal shovels, placed in plastic bags or glass bottles, packed in ice and sent to a certified laboratory for analysis.

2.7 Remediation of Timber-Contaminated Soils

Study methods of soil remediation are reported for Garden 2 because remediation funds were available to BNAN for that garden. Timbers were removed from Garden 2 and disposed of by BNAN as hazardous waste. The soils located 6-8" from both sides of the timbers and to a depth of 6-8" were removed and mixed in a 1 part soil to 2.5 parts compost at the facility which makes compost for the city of Boston. This recommended ratio of 1:2.5 was based on a comparison of concentrations of PAHs from municipal compost and PAHs from the most contaminated soils, adjacent to the timbers. The soil: compost mixture was characterized by six samples, each reflecting a composite of six pooled samples. Samples were collected with clean metal shovels, placed in glass bottles, packed in ice and sent to the EPA laboratory or a certified laboratory for analysis. The samples were analyzed only for PAHs, lead and arsenic.

2.8 Survey of Boston Community Gardeners

A closed-ended survey with questions on safe gardening practice and crop preferences was administered anonymously to participants at a BNAN-sponsored workshop at the beginning of the 2006 gardening season. Participation in the survey was voluntary; and 79 of the 114 gardeners (69%) present at the event completed the survey. This convenience sample represented approximately 10% of the community gardeners in Boston. The purpose of the survey was to get a better understanding of the demographics and practices of the gardeners in order to provide recommendations that are most meaningful and relevant.

3. RESULTS AND DISCUSSION

3.1 PAH Concentrations in garden plots bordered by creosote timbers

Soil concentrations at each distance are given in Table 1 for 16 PAHs and for total PAHs. All of the analyzed PAHs were detected adjacent to the timber. Of the carcinogenic PAHs, benzo(a)pyrene, benzo(a)anthracene and benzo(b)fluoranthene predominate adjacent to the timber. Of the non-carcinogenic PAHs, fluoranthene and pyrene are the dominant species. On average, the concentration of total PAHs in soil within 18 inches of creosote timbers was four times that of concentrations found in the center of garden plots and more than five times that of background PAH concentrations.

Polycyclic aromatic hydrocarbon concentrations were highest in soil sampled adjacent to the timbers with concentrations decreasing with increasing distance out to 18 inches, eventually approaching background concentrations as shown in Figure 1. The association between distance from the creosote timbers and change in PAH concentrations was found to be significant, as tested by Spearman's rank correlation, for all individual PAHs and their sum, with the exception of naphthalene (Table 1).

No significant difference was found in overall or individual PAH concentrations among the three plots sampled except for phenanthrene, which was found to be significantly higher in Garden 1 than in either of the plots in Garden 2 (p=0.0239). Similarly, no significant difference was found in PAH concentrations between the two depths, 0-4 inches and 4-8 inches for all distances and analytes measured. Therefore further analyses were not stratified by plot or depth. Concentrations of all individual PAHs were not statistically lower in the background samples compared with the samples taken from the center of the garden plots.

	Edge[a] (n=24)				Center[b] (n=3)				Bkgd (n=2)			
Analyte	Detect (%)	GM (mg/kg)	GSD (mg/kg)	Range[c] (mg/kg)	Detect (%)	GM (mg/kg)	GSD (mg/kg)	Range[c] (mg/kg)	Detect (%)	GM (mg/kg)	GSD (mg/kg)	Range[c] (mg/kg)
Non-carcinogenic PAHs												
Acenaphthene	17	<2.20[d]	[e]	0.55 - 1.2	0	<0.49[d]	[e]	-	0	<0.50[d]	[e]	-
Acenaphthylene	92	1.69	3.09	0.44 - 12.0	33	<0.49[d]	[e]	0.45 - 0.45	0	<0.50[d]	[e]	-
Anthracene	96	1.87	2.97	0.52 - 14.0	67	0.46	1.89	0.51 - 0.83	50	<0.50[d]	[e]	0.48 - 0.48
Benzo(g,h,i)perylene	100	2.72	2.70	0.75 - 19.0	100	0.62	1.18	0.55 - 0.75	50	<0.52[d]	[e]	0.52 - 0.52
Fluoranthene	100	8.72	3.77	0.56 - 93.0	100	2.74	1.29	2.10 - 3.50	100	2.00	1.37	1.60 - 2.50
Fluorene	42	<4.00[d]	[e]	0.55 - 4.0	33	<0.55[d]	[e]	0.55 - 0.55	50	<0.50[d]	[e]	0.27 - 0.27
Naphthalene	13	<2.20[d]	[e]	0.51 - 1.1	33	<0.64[d]	[e]	0.64 - 0.64	0	<0.50[d]	[e]	-
Phenanthrene	100	3.46	3.11	0.73 - 35.0	100	1.79	1.55	1.10 - 2.60	100	1.69	1.18	1.50 - 1.90
Pyrene	100	9.87	3.01	2.25 - 85.0	100	2.18	1.31	1.60 - 2.60	100	1.65	1.04	1.60 - 1.70
Carcinogenic PAHs												
Benzo(a)anthracene	100	5.51	3.00	1.30 - 43.0	100	1.10	1.44	0.74 - 1.50	100	0.90	1.34	0.73 - 1.10
Benzo(a)pyrene	100	4.06	2.86	1.03 - 28.0	100	0.88	1.36	0.65 - 1.20	100	0.69	1.33	0.56 - 0.84
Benzo(b)fluoranthene	100	6.80	2.79	1.90 - 51.0	100	1.37	1.32	1.00 - 1.70	100	0.74	1.97	0.46 - 1.20
Benzo(k)fluoranthene	100	2.01	2.60	0.55 - 12.0	33	<0.57[d]	[e]	0.57 - 0.57	50	<0.50[d]	[e]	0.42 - 0.42
Chrysene	100	5.13	2.74	1.35 - 34.0	100	1.12	1.30	0.84 - 1.40	100	0.86	1.24	0.74 - 1.00
Dibenzo(a,h)anthracene	71	0.82	2.85	0.46 - 5.6	0	<0.49[d]	[e]	-	0	<0.50[d]	[e]	-
Indeno(1,2,3-cd)pyrene	100	3.34	2.72	0.90 - 20.0	100	0.76	1.20	0.65 - 0.92	50	<0.65[d]	[e]	0.65 - 0.65
Non-carcinogenic Total[f]		**31.71**	**2.88**	**6.86 - 264.0**		**9.10**	**1.34**	**6.53 - 11.00**		**6.97**	**1.22**	**6.05 - 8.03**
Carcinogenic Total[f]		**27.75**	**2.81**	**7.49 - 194.0**		**5.80**	**1.32**	**4.35 - 7.53**		**4.15**	**1.46**	**3.17 - 5.43**
Total PAHs[f]		**59.62**	**2.84**	**14.40 - 458.0**		**14.93**	**1.32**	**10.90 - 18.00**		**11.14**	**1.31**	**9.22 - 13.50**

[a]Edge samples are those collected from within 18" of a creosote timber.
[b]Center samples are composites of soil collected from the center of a plot and 30" from surrounding creosote timbers.
[c]Range of detected samples only.
[d]GM not calculated where analyte was undetected in 50% or more samples. The greater of the maximum value detected or the detection limit is shown.
[e]Geometric standard deviation (GSD) not shown due to low level of detection.
[f]Totals were calculated using half of the detection limit for undetected samples.

Table 1. PAH concentration in soil by distance from creosote timbers and results of correlation analyses

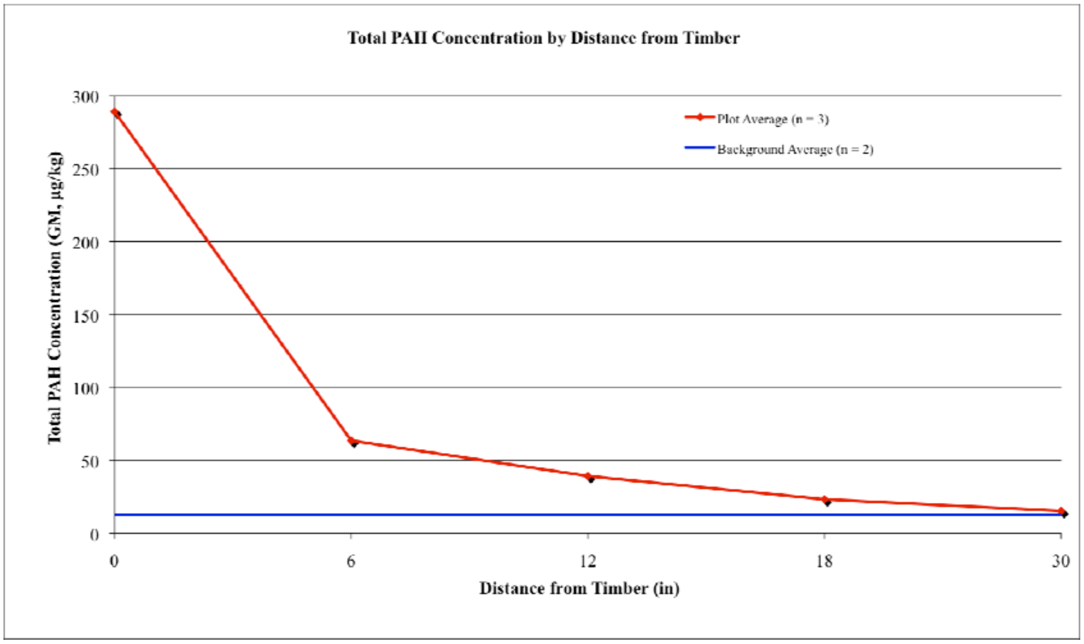

Figure 1. Change in total PAH concentrations from three garden plots by distance from creosote timbers compared to the background average.

3.2 Arsenic concentrations in CCA-bordered garden plots

A total of 24 soil samples were collected from garden plots bordered by CCA-treated timbers in the two gardens. In 18 of the 24 samples, arsenic levels were below the detection limit of 20 mg/kg. Of the remaining 6 samples, all were taken from within 3 inches of the timbers, with no appreciable difference found between those taken at a soil depth of 0-4 inches and 4-8 inches. The arsenic in these samples ranged from 30-39 mg/kg (data not shown).

3.3 Compost Contaminants

Samples from the city compost (without street sweepings) contained very low concentrations of PAHs, phthalates, arsenic, lead and other metals. As shown in Table 2, the concentrations of PAHs in compost are well below the concentrations measured in garden soil adjacent to the creosote timbers, and lower than concentrations in background samples. Concentrations of lead range from 117 mg/kg to 170 mg/kg, with a mean of 130 mg/kg. A sample of city compost to which street sweepings were added contained several PAHs (benzo(a)pyrene, benzo(a)anthracene, and benzo(b)fluoranthene) with concentrations that exceeded background levels of PAHs (data not shown).

Analyte	DR (%)	Mean[1] (μg kg^{-1})	SD (μg kg^{-1})	Median (μg kg^{-1})	Min. (μg kg^{-1})	Max. (μg kg^{-1})
Metals (n = 7)						
Arsenic	100	3914.3	1294.1	3400	2100	2100 - 5700
Lead	100	138100.0	21661.4	130000	117100	117100 - 170000
Non-Carcinogenic PAHs (n = 10)						
Acenaphthene	20	91.5	96.9	91.5	ND	160
Acenaphthylene	10	110.0	NA	110	ND	110
Anthracene	30	143.6	168.9	100	ND	330
Benzo(*g,h,i*)perylene	80	355.7	187.7	419.5	32.1	588
Fluoranthene	100	909.6	721.9	756	53.1	2800
Fluorene	20	98.0	73.5	98	ND	150
Naphthalene	20	39.0	35.4	39	ND	64
Phenanthrene	60	431.8	601.1	265	1	2000
Pyrene	100	640.0	587.4	394	50.9	2100
Carcinogenic PAHs (n = 10)						
Benzo(*a*)anthracene	100	455.9	303.1	406	88.5	1200
Benzo(*a*)pyrene	100	549.9	338.0	435	37.1	1270
Benzo(*b*)fluoranthene	100	813.1	646.2	760.5	73.9	2471
Benzo(*k*)fluoranthene	100	498.8	471.6	368.5	67.7	1764
Chrysene	100	554.9	267.4	555	171.0	1000
Dibenzo(*a,h*)anthracene	40	79.5	61.0	73.8	ND	150
Indeno(1,2,3-*cd*)pyrene	90	347.4	154.5	386	41.9	515
Totals						
PAHs	100	5688.6	3240.151	4890.25	1318.8	13394
Non-Carcinogenic PAHs	100	2436.9	2111.128	1955.25	137.1	8064
Carcinogenic PAHs	100	3251.7	1604.948	2552.5	1181.7	6522.2

DR: detectable ratio; ND: under detection limit.
[1] Arithmetic mean
(μg kg^{-1}) = micrograms per kilogram (parts per billion, ppb)

Table 2. Summary statistics PAHs, arsenic (As), and lead (Pb) in compost (μg/kg)

3.4 Soil Concentrations of PAHs Following Remediation

Following removal of creosote timbers and dilution of soils with clean compost in the remediation garden (Garden 2), the concentration of PAHs decreased, as expected, as shown in Figure 2. With one exception, benzo(a)pyrene, the concentrations of individual PAHs are lower than the standards set by the Massachusetts Department of Environmental Protection (MADEP) for residential soils known as the MADEP S1 Standards. The mean benzo(a)pyrene concentration before remediation was 4.06 mg/kg and following remediation was 2.42 mg/kg compared to its S1 standard of 2 mg/kg.

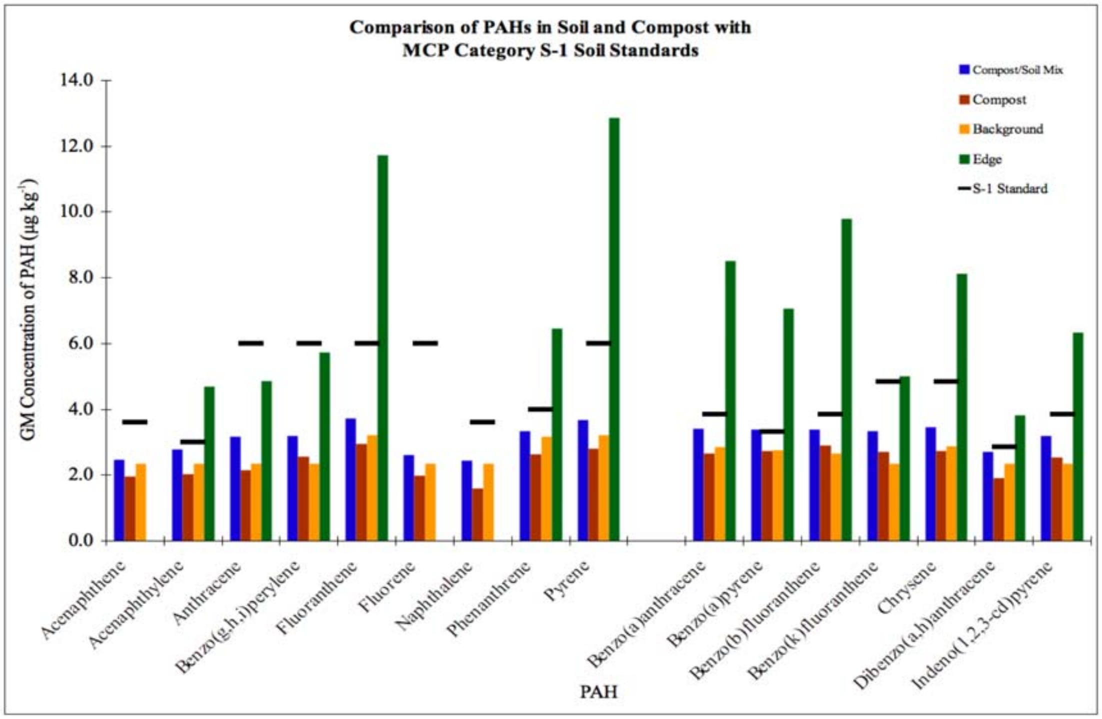

Figure 2. PAH concentration in pre- and post-remediated soil compared with residential soil standards

3.5 Survey of Gardeners

Key results of the gardener's survey are shown in Table 3. The majority of those surveyed are female, with nearly half of the population older than 45 years. About one-third of the gardeners had children present when gardening. Nearly all gardeners consumed the food grown in their gardens and a small number (4%) relied entirely on their home-grown produce for their summer and fall source of vegetables (not shown). While the majority of these urban plots are small, a large number (70%) of those surveyed preserve or dry their produce for consumption later in the year. The most commonly grown crops were tomatoes, lettuce, onions, collards, and cucumbers, with evidence of cultural preference in the vegetables grown. As demonstrated by the survey results, the community gardens in Boston are used by people of all ages, growing food for consumption.

Gardener Demographics	
Female	73%
Age (>45 yrs)	45%
Garden with children	34%
Gardening Behavior	
Dig Deeper than 1'	30%
Wear gloves (all the time)	47%
Food Growing & Consumption	
Wash hands after gardening	99%
Eat produce	99%
Can or preserve foods	70%
Crop Preference	
Vegetables	97%
Herbs	91%
Fruit	62%

Table 3. Summary of key findings reported by community gardeners

3.6 Discussion

Polycyclic aromatic hydrocarbons are multi-ringed chemical structures with the greater ringed structures presenting both a greater health hazard and a greater resistance to breakdown in soil. Because PAHs are relatively hydrophobic, they can be persistent in the environment, particularly in soil and in sediment. PAHs have been well studied and much about their behavior in the environment is understood. However, data regarding the migration and transport patterns of PAHs from creosote timbers have been limited to studies of aquatic environments and along railroad beds. This study is unique in its measurement of the transport of PAHs in garden soil from creosote timbers. The concentrations of both carcinogenic and non-carcinogenic PAHs exceed the Massachusetts Department of Environmental Protection's S1 Standards, concentrations allowable for residential soils. As demonstrated in the analyses, the concentration of PAHs as a mixture is significantly higher adjacent to and out to 18 inches of the timbers than background levels, with most of the PAHs dropping below the S1 Standards between 6"-12". The PAH with the lowest S1 Standard is benzo(a, h)anthracene, however its concentration at and beyond the timbers is low, compared with the concentration at the timber and beyond for benzo(a)prene. Since the S1 Standard for benzo(a)pyrene is lower than that for the other individual PAHs, benzo(a)pyrene can be used as a guide for reaching urban background soil concentrations. Because of anthropogenic sources of PAHs, concentrations are typically higher in the urban environment than in pristine environments and often these S1 standards are exceeded for urban soils, in the absence of an identifiable source.

Boston residential yard waste is the only feedstock source for municipal compost. Thus, source separation and potential for elevated concentrations of contaminants is less of an issue for Boston compost than with more complex municipal programs that accept a variety of source materials (C. Ambrose Evans, 2006, unpublished). Residents collect and bag yard waste which is picked up curbside by the municipal composting truck. The contents are hauled to a municipal composting facility where the bags are ground by tub grinder and placed in outdoor windrows for about a year, or until the space is needed for new feedstock. The windrows are forced through a screener, which removes larger debris, such as rocks or woody material that has not fully composted, before distribution.

Field and laboratory studies have been conducted that examine the effects of composted material on the composition and concentration of PAHs. Various types of environmental conditions are supportive of the degradation. Both indigenous soil bacteria and various types of fungi which are present in compost have been shown to successfully degrade PAHs. Some key principles of PAH degradation are that many naturally occurring bacteria and fungi are capable of metabolizing PAHs; that oxygen must be present for the breakdown process, and that lower-weight PAHs degrade rapidly while higher ring PAHs are resistant to microbial breakdown (Crawford et. al. 1993). However, even in the case of the higher-ring PAHs, albeit when PAH concentrations are in the part per million range, there is evidence that a combination of remediation steps may have the potential to sufficiently degrade the PAHs (Kästner and Mahro 1996). Thus "clean" compost is a beneficial soil amendment in urban community gardens as both a dilution agent and also as a stimulant for biodegradation of PAHs.

The uptake of PAHs by vegetables and fruits grown in contaminated soils appears to be minimal (Kipopoulou et al. 1999, Samsoe-Peterson et al. 2002, Schnoor et al. 1995). The hydrophobic nature of PAHs prevents translocation into the inner root system of plants (Samsoe-Peterson et al. 2002, Schnoor et al. 1995, Simonich et al. 1995). However, PAHs have been found in vegetables. This is thought to be from atmospheric deposition of PAHs on leaves of plants (Samsoe-Peterson et al. 2002). Carrots, which have a high lipid content, have been observed to have levels of PAHs that may be a result of growth in contaminated soils (Samsoe-Peterson et al. 2002); therefore, these might be avoided when choosing crops to grow or be peeled before eating. A recent study demonstrated that small molecular weight PAHs, were found in oil extracted from olives collected in a rural area where old railway ties were stored (Moret et al. 2007).

Due to the limited uptake of PAHs by plants, there are three routes of exposure to the PAHs that must be considered: inhalation of volatized PAHs or soil particles; ingestion of soil; and dermal contact with soil. Because the PAHs of concern do not volatilize easily, our recommendations below focus on good gardening practices to minimize ingestion and dermal contact. Young children should be carefully monitored in the garden area to prevent "curious ingestion" of the soil. In general, thorough washing of all items harvested from the garden is advisable and will help prevent exposure to PAHs, whether from soil on the plant surface, or from atmospheric deposition. To avoid dermal contact, gloves and proper clothing should be worn while working the garden. Immediately after gardening, hands and shoes should be washed.

The soil sample results obtained from the CCA timber-containing garden (not shown) are consistent with the literature. In an experimental study by Lebow et al. (2004a), arsenic concentrations were measured in the soil adjacent to CCA-treated wood stakes. The highest concentrations were found within 5cm laterally of the stakes. At 6 inches, samples were much less likely to contain elevated concentrations of CCA components as compared to background levels. In an observational study by Rahman et al. (2004), soil samples were collected adjacent to CCA-treated lumber in six established raised garden beds, each approximately 10 years old. Fifteen cm core samples were taken at distances of 0-2, 7.5-10, and 30-33 cm from the lumber.

Highest concentrations of arsenic in soil were found 0-2 cm from the wood, with a steady decline in concentration at greater distances. No samples beyond 10 cm were found to contain arsenic at a concentration greater than 20 mg/kg.

Accumulation of arsenic in soil is a function of both the rate of leaching from the timbers and their subsequent mobility in the soil. Lebow et al. (2004b) reviewed the results of numerous studies on wood preservative leaching and environmental accumulation and found that, "regardless of specific conditions, it is likely that rate of leaching occurring during the first year of exposure [to the elements] will be greater than that during subsequent years." It has also been found that arsenic tends to be quite immobile in soil (Lebow et al. 2004a, Lebow et al. 2004b).

Methods are available to measure the uptake of arsenic and chromium in plants (roots, seeds, fruit) and to determine the mobility of the metal in the soil and its potential for uptake into plants. The literature strongly supports the conclusion that little chromium and arsenic is transported to storage organs of plants (seeds & fruit), but that underground plant tissues can be contaminated by virtue of the adsorption of soil adhering to the plant (Rahman et al. 2004 and others). Most of the data on plant uptake have been collected from soils that contain concentrations of arsenic that exceed 50 mg/kg. The most important potential transfer of soil arsenic is soil particles bound to the skin of root vegetables. Continuing studies are evaluating the affects of soil amendments such as iron, phosphate, sulphates, and organic content on the ability of soils to adsorb arsenic.

4. CONCLUSION

4.1 Safe Work and Treatment Practices

An effective, low cost solution to the contamination of garden soil by PAHs derived from creosote-containing timbers is recommended based on the results of the analyses conducted in this body of work. The recommendations derive from the behavior of benzo(a)pyrene in the soil. Removal of the timbers is necessary, as they remain a continuous source of PAHs that will, in time continue to contaminate the soil. Any removal actions require notification and opportunity for discussion with gardeners and garden owners/managers. The work of remediation should be conducted on days when the wind is minimal and workers should wear garden work gloves. The timbers should not be burned, nor disposed of in the regular trash. They should be disposed according to state regulation. If possible, community garden associations should mix soil beneath and adjacent to creosote timbers to a distance of 18 inches from the timber and a depth of 8 inches with clean compost in the ratio of 1 part soil and 1 part compost. Or, if not feasible, they can mix soil beneath and adjacent to creosote timbers to a distance of 9 inches and a depth of 8 inches with clean compost in the ratio of 1 part soil and 3 parts compost. The mixture would be placed into the excavated areas. Extra soil/compost mixture can be spread throughout the garden. Due to the elevated concentrations of PAHs detected in the batch of compost that contained street sweepings, we recommend that only compost without street sweepings be added to community garden soil. The addition of clean compost with PAHs and metals in concentrations well below the MADEP soil residential standards will serve to a) provide a source of microorganisms that may assist in the breakdown of the PAHs and b) dilute any remaining PAHs present in garden soil.

Since most As leaching occurs during the first year of use and much of the leached arsenic remains near to the timber, we conclude that CCA lumber used for any length of time in the gardens should be removed and the adjacent soil, to a distance of 3 inches and depth of 8 inches, replaced with clean city compost or diluted in a 1:1 ratio with clean city compost. This conclusion is supported by results of As-contaminated soil diluted with City of Boston compost as shown in Figure 3 (Wellesley College, October 2007), bringing the concentration of As in soil well below the MA DEP S1 Standard.

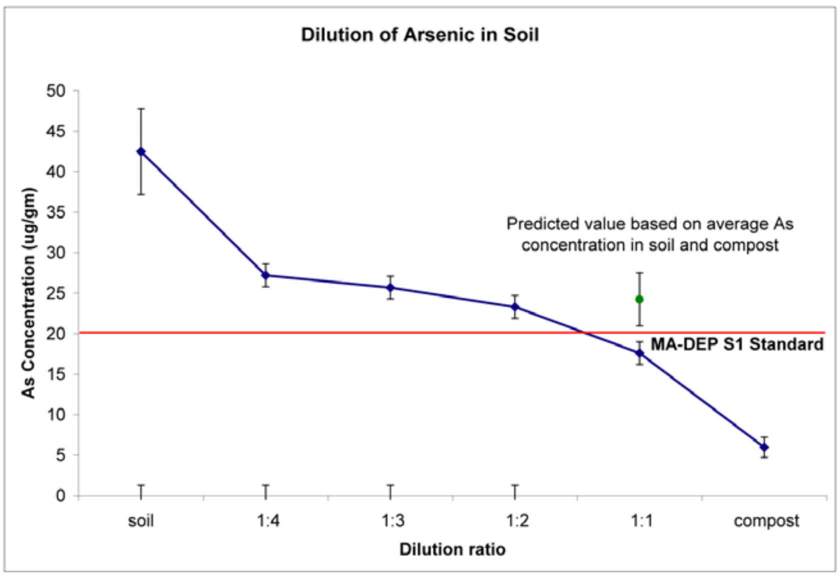

Figure 3. Dilution of Copper, Chromium, and Arsenic in Garden Soil by the Addition of Compost

4.2 Gardener Education

We strongly recommend that education continue with gardeners through annual meetings, newsletters, gardeners spring clean up meeting in their own gardens, and through the Master Urban Garden class. These venues provide the opportunity to disseminate information about good gardening practices such as wearing gloves, leaving gardening shoes at the door, washing produce before eating, adding clean organic matter to soil, and using mulch to lessen splashing of soil onto plants.

PAHs are ubiquitous and will continue to deposit on the garden soil from the air, which is continuously being polluted by combustion from cars, industry, and home heating systems. By following the suggestions mentioned above community gardeners can reduce their exposure while enjoying the benefits of gardening.

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